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COLLISIONS BETWEEN WEST FORD NEEDLES AND MICROMETEORITES

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COLLISIONS BETWEEN WEST FORD NEEDLES AND MICROMETEORITES.

ABSTRACT

Over a period of eight years there are sufficient collisions of micrometeorites with the needles of Project West Ford to break most of them.

INTRODUCTION.

In their study of the properties of the belt of needles from project West Ford, W.E. Morrow Jr. and D.C. MacLellan[1] have compared collisions between the needles and a metallic surface in the belt and between micrometeorites and a surface. They have shown that satellites and cosmic rockets have more chance to meet dust of interplanetary space than the dipoles (this being due above all to the short time needed to cross the belt).

An equally interesting problem is that of needle-micrometeorite collisions to know if these will break the dipoles or even reduced them to small dust particles. Our calculation shows this phenomenon to be of real importance.

DATA ON MICROMETEORITES.

The table reviews what is at present known about micrometeorites near Earth.

The first two columns give respectively the magnitude M (extrapolated from the visual magnitude of meteorites) and the mass m of the micrometeorites, where following Whipple[2] :

$$M = 2,512 \log_{10} \frac{m_o}{m} \quad \text{with } m_o(M = 0) = 25 \text{ gr.}$$

The next two columns indicate the specific mass ρ and the radius R of the dust particles if supposed to be spherical; there is a minimum radius corresponding to the relation[3] :

$$R_{min} \cdot \rho = 0,6.10^{-4} \qquad \text{(C.G.S.)}$$

for which the solar gravitational attraction is equal to the solar radiation pressure.

M	m(gr)	ρ(gr cm^{-3})	R(μ)	v(km sec^{-1})	$\bar{E}$(erg)	$\bar{F}$(cm^{-2} sec^{-1})	D(cm) Al	Nr of collisions per year	D_{cu}(cm)
15	2.5×10^{-5}	0.05	492	20	$5,1\times10^{7}$	6.7×10^{-14}	1.3×10^{-1}	3.4×10^{-8}	1.1×10^{-1}
16	9.95×10^{-6}	0.05	362	19	1.83×10^{7}	3.1×10^{-13}	9.4×10^{-2}	1.6×10^{-7}	8.3×10^{-2}
17	3.96×10^{-6}	0.05	266	18	6.55×10^{6}	1.5×10^{-12}	6.8×10^{-2}	7.5×10^{-7}	$6\ \times10^{-2}$
18	1.58×10^{-6}	0.05	196	17	2.33×10^{6}	7.3×10^{-12}	4.9×10^{-2}	3.7×10^{-6}	4.4×10^{-2}
19	6.28×10^{-7}	0.05	144	16	8.2×10^{5}	3.4×10^{-11}	3.5×10^{-2}	1.7×10^{-5}	3.1×10^{-2}
20	2.5×10^{-7}	0.05	106	15	2.87×10^{5}	1.7×10^{-10}	2.5×10^{-2}	8.5×10^{-5}	2.3×10^{-2}
21	9.95×10^{-8}	0.05	78	15	1.14×10^{5}	7.7×10^{-10}	1.9×10^{-2}	3.9×10^{-4}	1.7×10^{-2}
22	3.96×10^{-8}	0.05	57.4	15	4.55×10^{4}	3.8×10^{-9}	1.4×10^{-2}	1.9×10^{-3}	1.2×10^{-2}
23	1.58×10^{-8}	0.06	39.8	15	1.81×10^{4}	1.9×10^{-8}	$1\ \times10^{-2}$	9.5×10^{-3}	$9\ \times10^{-3}$
24	6.28×10^{-9}	0.09	25.1	15	7.21×10^{3}	8.7×10^{-8}	7.4×10^{-3}	4.4×10^{-2}	6.6×10^{-3}
25	2.5×10^{-9}	0.16	15.8	15	2.87×10^{3}	4.3×10^{-7}	5.5×10^{-3}	2.2×10^{-1}	4.9×10^{-3}
26	9.95×10^{-10}	0.24	10	15	1.14×10^{3}	$2\ \times10^{-6}$	$4\ \times10^{-3}$	1	3.6×10^{-3}
27	3.96×10^{-10}	0.38	6.3	15	4.55×10^{2}	9.7×10^{-6}	$3\ \times10^{-3}$	4.9	2.6×10^{-3}
28	1.58×10^{-10}	0.6	3.98	15	1.81×10^{2}	4.6×10^{-5}	2.2×10^{-3}	2.3×10	$2\ \times10^{-3}$
29	6.28×10^{-11}	0.95	2.51	15	7.21×10^{1}	2.1×10^{-5}	1.6×10^{-3}	1.1×10	1.4×10^{-3}
30	2.5×10^{-11}	1.51	1.58	15	2.81×10	7.5×10^{-5}	1.2×10^{-3}	3.8×10	$1\ \times10^{-3}$
31	9.95×10^{-12}	2.4	1	15	1.14×10	1.8×10^{-4}	8.7×10^{-4}	$9\ \times10$	7.7×10^{-4}
32	3.96×10^{-12}	3.5	0.65	15	4.45	5.5×10^{-4}	6.4×10^{-4}	2.7×10^{2}	5.7×10^{-4}
33	1.58×10^{-12}	3.5	0.48	15	1.77	1.7×10^{-3}	4.7×10^{-4}	8.5×10^{2}	4.2×10^{-4}
34	6.28×10^{-13}	3.5	0.35	15	7.06×10^{-1}	$5\ \times10^{-3}$	3.4×10^{-4}	2.5×10^{3}	3.1×10^{-4}
35	2.5×10^{-13}	3.5	0.25	15	2.81×10^{-1}	1.7×10^{-2}	2.5×10^{-4}	8.5×10^{3}	2.2×10^{-4}
36	9.95×10^{-14}	3.5	0.19	15	1.12×10^{-1}	4.3×10^{-2}	1.9×10^{-4}	2.1×10^{4}	1.7×10^{-4}

The fifth and sixth columns give the speed v and the corresponding kinetic energy E ($= \frac{1}{2}\, m\, v^2$).

The seventh column gives, for each value of the mass m, the flux of particles of mass more than or equal to m according to the law :

$$\log_{10} F(\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}) = -1{,}7 \log_{10} m(\mathrm{gr}) - 21 \quad (10^{-10}\,\mathrm{gr} \leqslant m \leqslant 10^{-6}\,\mathrm{gr})$$

$$= -1{,}18 \log_{10} m(\mathrm{gr}) - 16{.}7 \quad (m < 10^{-10}\ \mathrm{gr}).$$

These empirical relations between the flux and the mass of the micrometeorites, due to M. Dubin et al[4] and to L.D. Jaffe et al[12] respectively, seem to account best for the recent satellite observations[5-16]; other proposed relations take the form[2,17-22]

$$\log_{10} F = -A \log_{10} m - B$$

where

$$1 \leqslant A \leqslant 1{,}7 \qquad 15{,}6 \leqslant B \leqslant 21.$$

The satellites and space probes reveal the presence of a cloud, or at least a maximum of dust particles around the Earth (in circumterrestrial orbits)[23-27] as the theoretical calculations predict[28-32].

The eight column gives the depth of penetration of the micrometeorites D into an aluminium surface. The formula used, due to R.L. Bjork[22], is valid for thick planar targets of aluminium and spherical incident projectiles of aluminium :

$$D = 1{,}09\, (mv)^{1/3}$$

with D in cms, m in grs and v in km sec^{-1}.

This relation has been derived theoretically from the following hypotheses ("hypervelocity impact") : normal incidence of the projectile, a hemispherical crater of radius D formed by the shock, the incident particle and the target obeying the laws of hydrodynamics at the time of the collision (because of the high speed of the meteorites), formation of a shock wave, negligible heat transfer and viscosity effects, fusion and evaporation unimportant for the penetration.

Numerous other theories have been proposed for the depth of peneratrion where D is expressed as a function of the momentum or the energy of the incident particle and of other characterizing properties of the target (specific mass, heat of fusion and vaporisation, speed of sound in the material, modulus of elasticity,....)[2, 4, 9, 17-19, 33-35]. The initial kinetic energy is converted by various mechanisms : radiation, ionisation, evaporation, fusion, deformation,... D.B. Beard[35] proposes the following formula :

$$D = \left[\frac{3\,E}{\pi \rho\, c\, Q} \right]^{1/3}$$

where Q is the heat of vaporisation of the target in erg gr^{-1}. This formula is easily interpreted by supposing that that volume of the crater ($2/3\ \pi D^3$) is twice the ratio of the kinetic energy of the incident particle to the heat of vaporisation of the target ($\rho c Q$).

For a target of aluminium, the results of Beard and of Bjork are nearly identical.

Bjork's formula seems to be better not only because it takes into account the hydrodynamic behavior of the material (necessitating moreover long numerical integrations), but essentially because it is confirmed by experiment. As meteorite speeds cannot yet be given experimentally to particles of well defined masses, the laws deduced for D can only be checked at low speeds (a few km sec^{-1}) and their domain of validity is uncertain.

Bjork finds D to vary slowly with the density of the incident particle (probably like $\rho^{-0.18}$), though like $\rho_c^{-1/2}$ with the specific mass of the target; for oblique incidence, D depends on the normal component of the velocity; he remarks too that for a thin target, the penetration depth is 1.5 D.

THE WEST FORD NEEDLES.

The last two columns of the table concern the project West Ford needles. The total surface of a cylinder of length ℓ and diameter d ($\ll \ell$) is

$$\pi d \ell + \frac{1}{2} \pi d^2 \simeq \pi d \ell = 1.59 \times 10^{-2} \text{ cm}^2.$$

The number of collisions per needle per year can be easily derived. The penetration depths in a copper needle can be obtained by multiplying $D_{A\ell}$ by

$$1.5 \times \left(\frac{\rho_{A\ell}}{\rho_{Cu}}\right)^{1/2} = 0.83$$

REMARKS ON THE PRECISION OF THE CALCULATIONS.

The last column of the table has been calculated for the case of a planar copper target perpendicular to the incident direction of the projectile : it is difficult to predict exactly what will happen for a fine needle. If the crater were perfectly hemispherical and nearly symmetric about the axis of the dipole, it could be said that it would break for $D \geqslant 28.6\ \mu$ (diameter of the needle). In fact the process is more complex : craters are formed all across the width of the curved surface presented by the cylinder and may have any shape according to that of the micrometeorite (see reference [26] for non-spherical μ meteorites); and crevasses are certainly formed around the holes.

There is a further uncertainty of a factor of 3 in the theoretical values for D due to incomplete knowledge of the dependence of D on the various parameters of the target and of the projectile [4].

It is thus difficult to say exactly what depth of penetration will lead to breaking the needle (perhaps $D \geqslant 10$-20μ).

There are yet other uncertainties in the micrometeorite data : distribution in mass (also $1 \leqslant m_o \leqslant 25$ gr), specific mass (between 5×10^{-2} and 3.5 gr cm^{-3}), speed (20 - 60 Km sec^{-1} for dust in heliocentric orbits and 7 - 15 Km sec^{-1} for that captured by the Earth), distribution of flux with altitude, longitude, latitude[24] and time (one takes the swarms of meteors into account by multiplying the mean annual flux by 2.35)[33].

INTERPRETATION OF THE RESULTS.

The table shows that over the orbital lifetime initially predicted for whole needles (about 8 years[36]), each dipole in the belt will be struck more than once by a micrometeorite and will break at least once, on the understanding that the probability of breaking into bits is proportional to the surface left.

As every metallic fragment has as much chance as another to be broken anywhere along its axis, a ring of metallic fragments of all lengths but of the same diameter will be formed.

The lifetime of the reflecting ring, initially predicted as two years[36], will probably be reduced by a half or more : evidently the needles must be of the same length to be of value as half wave resonant dipoles.

As regards the orbital life of the belt, there are two possibilities depending on whether the principal force making the needles fall is the solar radiation pressure or the resistive Coulomb force.

If only the radiation pressure is important, the lifetime for a resonant orbit[36] is inversely proportional to the ratio A/m (ratio of the effective cross section to the mass of the satellite) and will not be changed by breaking the needles, since A/m for a thin cylinder ($d \ll \ell$) is independant of its length and is hence the same for all the bits assuming they have the form of a right cylinder (a good approximation in our case).

On the other hand, if we follow S. F. Singer[37] in expecting the Coulomb drag force to be preponderant, the orbital lifetime will be influenced. This mechanism leads to a reduction of the semi-major axis of the belt proportional to the ratio of the square of the electric capacity of the satellite to its mass C^2/m. For a thin wire, the ratio is

$$K \frac{\ell}{d^2 \left(\log_{10} \frac{2\ell}{d}\right)^2} \qquad (K = \text{constant})$$

and so varies principally as ℓ. The bits of needles would have in this case an orbital life inversely proportional to their length.

It is at the moment difficult to say which of these two effects will be the more important for the second is not yet well enough known from the motions of satellites.

If neither of these two forces is sufficient to shorten the orbital life (possible for several reasons : initial non-resonant orbit, overestimation of the Coulomb breaking force, ...), the dipoles will be reduced to progressively finer dust. One should add that optical and radio astronomy will be hindered more by the much more numerous fragments of needles than by the whole needles, above all for measurements of polarization.

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